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U.S. FISH & WILDLIFE SERVICE
REGION 6

ENVIRONMENTAL CONTAMINANTS PROGRAM

TRACE ELEMENTS IN THE AQUATIC BIRD FOOD CHAIN AT THE NORTH PONDS, TEXACO REFINERY CASPER, WYOMING

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ABSTRACT

The objectives of this study were to determine nesting success of aquatic birds, trace element concentrations in the aquatic food chain, and whether trace elements were biomagnifying through the aquatic food chain of ponds at the inactive Texaco Refinery, in Evansville, Wyoming. Trace element concentrations in samples collected from the Texaco Refinery were compared to those found in samples collected from a background site, Pathfinder National Wildlife Refuge.

The ponds at the inactive refinery provided a source of water to aquatic birds in an otherwise arid landscape. Nesting success for shorebirds using an island in Pond 1 was greater than 90%. Waterfowl used Pond 1 mainly to feed rather than for nesting. Little nesting activity was observed for waterfowl and shorebirds at Pond 2, but shorebirds were consistently observed feeding and resting there.

Trace elements in water samples from Ponds 1 and 2 were not at concentrations that could adversely affect feeding and nesting aquatic birds. Chromium was slightly elevated in sediments and in some vegetation and avian egg samples from both ponds relative to background concentrations. However, the potential for these concentrations to affect aquatic birds is unknown. Arsenic was slightly elevated in some sediment samples from both ponds but concentrations were comparable to background concentrations. Boron and selenium were slightly elevated in vegetation samples, and selenium was also slightly elevated in avian egg samples. Both boron and selenium are naturally occurring in the area which would explain the slight elevations found in the biological samples. There was no indication of significant bioaccumulation of any trace elements in the aquatic food chain.

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INTRODUCTION

The Texaco Refinery in Evansville, Wyoming (Figure 1), operated from 1923 to 1982. The North Platte River divides the property of the refinery into two separate properties, the North Property and the South Property. Groundwater collected by interceptor trenches, and occasional storm water runoff from the refinery on the South Property, is discharged into a series of ponds on the North Property. When the refinery was active, these ponds also received refinery process water from an inlet pond. The ponds provide habitat for a variety of migratory aquatic birds (TRC Environmental Corporation 1994) in the otherwise arid landscape.

TRC Environmental Corporation (1994) studied water and sediment quality at the refinery, the North Platte River, and the North Property ponds to determine the presence of hazardous waste. TRC found that lead in surface water and chromium in sediment from the North Property ponds were slightly elevated. Mercury and selenium were elevated in water samples taken from the North Platte River immediately upstream and adjacent to the refinery.

Because TRC identified the above listed trace elements as "constituents of concern," the collection of additional trace element data was necessary to determine if aquatic birds are impacted by trace elements in the North Property ponds. The objectives of this study were to determine nesting success of American avocets (*Recurvirostra americana*) and/or other aquatic birds, trace element concentrations in the aquatic food chain, and if trace elements were biomagnifying through the aquatic food chain to concentrations that could injure migratory birds.

STUDY SITES

When the refinery was active, process water was pumped to an inlet pond that discharged to Pond 1 on the North Property (Figure 2). Excess water from Pond 1 flowed to the remaining ponds. Currently, Pond 1 receives only groundwater collected by interceptor trenches and occasional storm water runoff.

We sampled Ponds 1 and 2. An island with limited vegetation in Pond 1 was used for nesting by American avocets and black-necked stilts (*Himantopus mexicanus*). There were no islands in Pond 2. Pond 1 lacked substantial stands of submergent and emergent vegetation, whereas the shallow Pond 2 had significant stands of cattails (*Typha latifolia*), sedges (*Eleocharis* sp.), and pondweed (*Potamogeton* sp.). An abundant aquatic invertebrate population was present at Pond 2 relative to Pond 1. There were no fish in the ponds. The surrounding terrestrial vegetation includes prairie grasses, sagebrush (*Artemisia* sp.), rabbit brush (*Chrysothamnus* sp.), and Russian olive trees (*Elaeagnus angustifolia*).

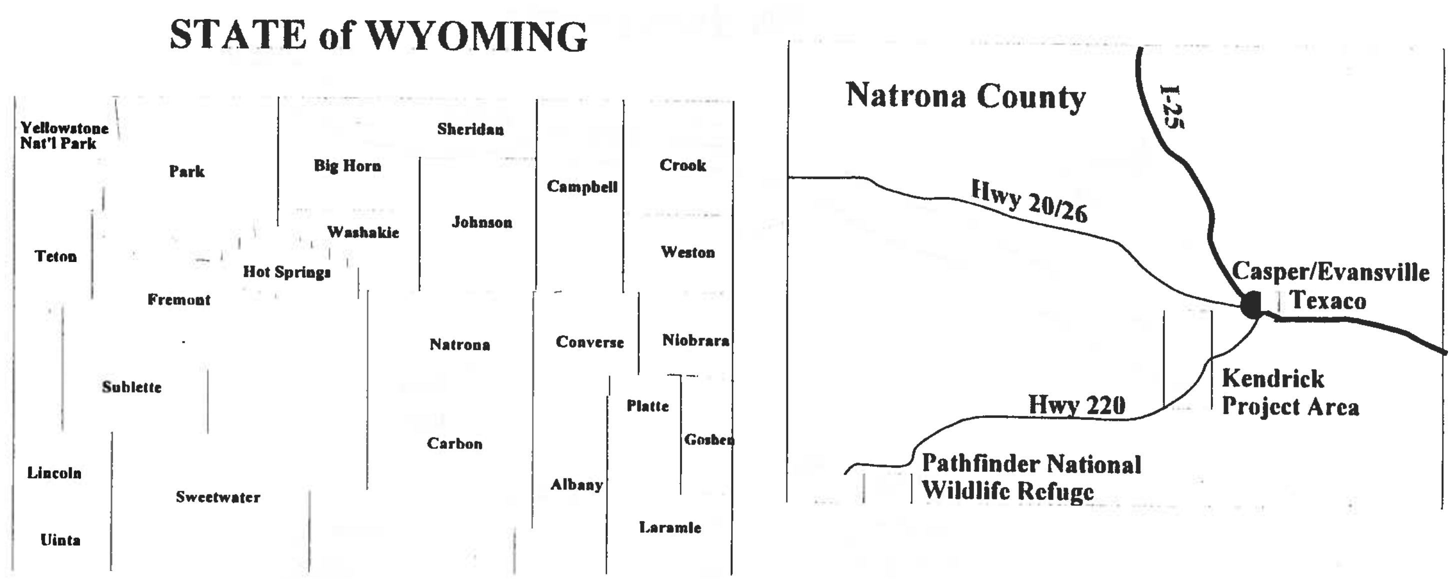

Figure 1. Map of Wyoming and general location of study area. Map not to scale.

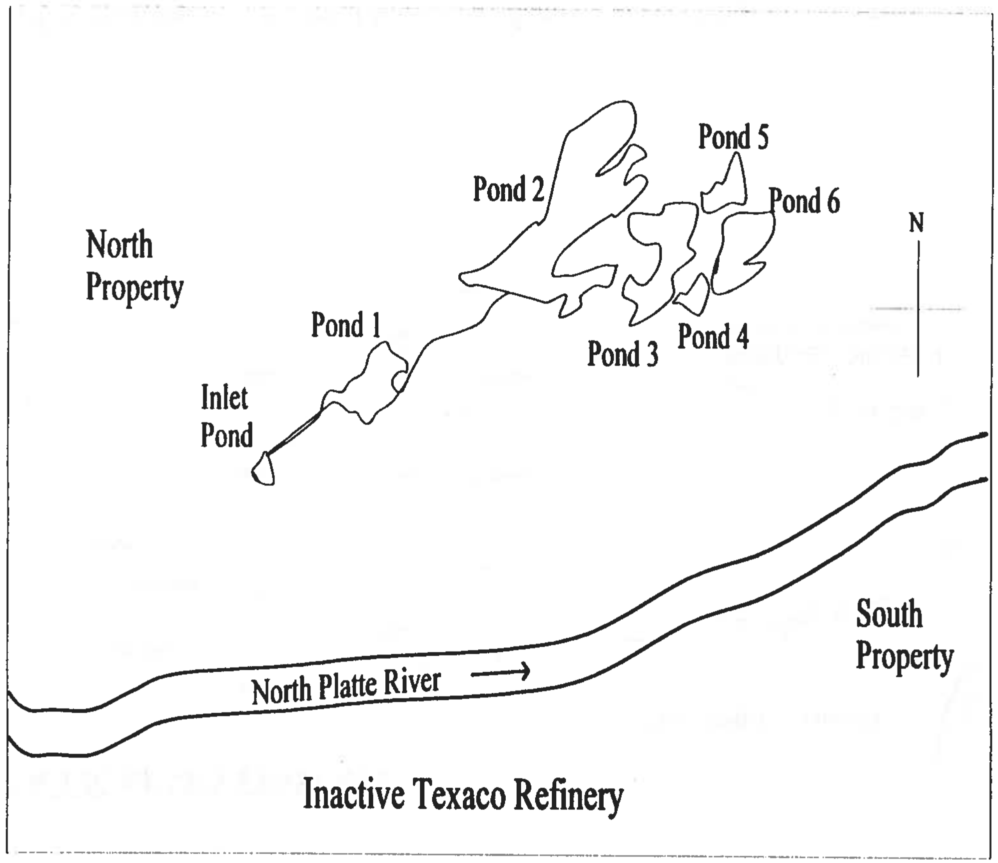

Figure 2. Location of the North Property Ponds.

METHODS

Data Collection and Analysis

We searched for waterfowl and shorebird nests each week in June and July 1997 at Ponds 1 and 2. Rope drags were used for searching the upland areas for duck nests. The shorelines of Ponds 1 and 2 and the island in Pond 1 were inspected visually for shorebird nests. The exact locations of the nests were plotted on a map so that nests could be rechecked without using markers that could serve as visual cues for predators. Nests and eggs in each nest were numbered consecutively using a waterproof marker.

We collected and dissected one egg from each nest. If the egg was viable, we aged the embryo and examined it for deformities. The egg contents were placed into 120-ml glass jars and frozen until trace element analysis was conducted. A hatching date was estimated based on the incubation period for the species. The nests were revisited during the estimated incubation period until hatching to determine the fate of the eggs. Data recorded at each nest followed that recommended by Klett et al. (1986).

We also collected water, sediment, aquatic vegetation, and aquatic invertebrates at Ponds 1 and 2. We used the U.S. Fish and Wildlife Service's standard operating procedures for environmental contaminant operations (Division of Environmental Contaminants, Quality Assurance Task Force 1996).

We collected five water samples from each pond at the beginning of the sampling season in May and June and again in August. The water was collected in 1000-ml chemically-clean polyethylene jars with teflon-lined lids that were rinsed three times with sample water. The samples were acidified with 70% nitric acid to a pH of <2 for trace element analysis. Duplicate water samples were collected and refrigerated until basic water chemistry analysis was conducted. Basic water chemistry analysis included: total alkalinity, total dissolved solids, sulfates, chlorides, bicarbonates, calcium, total cations and total anions.

We collected ten composite samples from the top six inches of sediment from each pond with a stainless steel spoon rinsed in de-ionized water and hexane. The sediment was placed in Whirl-pak® bags and frozen. Ten aquatic vegetation samples were collected by hand from each pond. The vegetation was placed in Whirl-pak® bags, and frozen. Ten aquatic invertebrates samples were collected from each pond using dip nets. The invertebrates were placed into 40-ml chemically-cleaned glass vials and frozen.

Samples were submitted to designated laboratories under contract with the Service's Patuxent Analytical Control Facility (PACF) at Laurel, Maryland, for trace element analyses. Trace element analysis included scans for arsenic and selenium using atomic absorption spectroscopy, mercury using cold vapor atomic absorption spectroscopy, and the remaining trace elements using inductively coupled plasma emission spectroscopy. Quality assurance and quality control of the chemical analysis were approved by the PACF. The water samples for basic water chemistry were analyzed by the Colorado State University Water Quality Laboratory in Fort Collins.

RESULTS AND DISCUSSION

Nesting Success

American avocets and black-necked stilts were the primary nesting species at Pond 1, nesting on the sparsely vegetated island. Two mallard (*Anas platyrhynchos*) nests were found at Pond 1, one on the island and the other on nearby upland habitat. One nest of unidentified duck species was found at Pond 2.

Results of nesting success are shown in Table 1. A successful nest was defined as one where at least one egg hatched, which was determined by the observation of pipping hatchlings or the presence of a detached shell membrane and small shell fragments if pipping hatchlings were not observed (Klett et al. 1983). All of the eggs were infertile in one of the mallard nests at Pond 1. The fate of the other mallard nest at Pond 1 and the duck nest at Pond 2 could not be determined but were probably destroyed by predators. Eared grebes (*Podiceps nigricollis*) were commonly sighted on Pond 1, and we found two eared grebe nests on the island's shoreline. However, the nests were flooded when water levels in the pond rose.

We found no Canada goose (*Branta canadensis*) nests at Pond 1 although two broods were observed swimming on the pond. Other species of waterfowl or shorebirds observed resting and feeding on or near Pond 1 included lesser scaup (*Aythya affinis*), redhead (*Athya americana*), widgeon (*Anas americana*), gadwall (*Anas strepera*), teal (*Anas sp.*), ruddy ducks (*Oxyura jamaicensis*), willits (*Catoptrophorus semipalmatus*), and killdeer (*Charadrius vociferus*). Waterfowl did not frequent Pond 2 but we regularly observed avocets, Wilson's phalaropes (*Phalaropus tricolor*), and coots (*Fulica americana*) feeding there. Phalaropes and coots also nested at Pond 2.

Table 1. Observations of nest fate from surveys conducted at Ponds 1 and 2 in May.

Site	Species	Infertile/ Addled	Destroyed	Fate Unknown	Successful	Total Nests
Pond 1	Mallard	1	--	1	--	2
	American Avocet	--	--	--	7	7
	Black-necked Stilt	1	--	--	5	6
	Eared Grebe[1]	--	2	--	--	2
Pond 2	Mallard	--	--	1	--	1

[1]Grebe eggs were fertile and in good condition. Nests were destroyed after water levels rose and flooded the nests.

Trace Elements

Water/Sediment

Basic water chemistry data are provided in Appendix 1. Water is primarily of the sodium sulfate type for both ponds, which is typical for the area (Ramirez et al. 1995). Trace element concentrations in water samples (Appendix 2) from Ponds 1 and 2 were either below detection limits or below levels that could adversely affect fish and wildlife resources.

Arsenic and chromium were slightly elevated in some individual sediment samples from Ponds 1 and 2 (Table 2, Appendix 3). Although there is currently no sediment quality criteria, the U.S. EPA uses the following classification when regulating dredged sediment in the Great Lakes: non-polluted (As = <3 μg/g; Cr = <25 μg/g), moderately polluted (As = 3 - 8 μg/g; Cr = 25 - 75 μg/g), and heavily polluted (As = > 8 μg/g; Cr = >75 μg/g) (Geisy and Hoke 1990). Other researchers proposed 17 μg/g and 100 μg/g as reasonable criteria for arsenic and chromium, respectively (Geisy and Hoke 1990). These guidelines are based on the toxicity of the elements to benthic invertebrates. The potential for bioaccumulation or sublethal effects to occur in species higher on the food chain or for longer-lived species is not considered. However, neither arsenic nor chromium is biomagnified through the food chain (Eisler 1986, 1988).

Additionally, analyses of sediments samples (n = 18) from Pathfinder National Wildlife Refuge in Natrona County (Ramirez, et al. 1995) showed a mean of 3.6 μg/g for arsenic (range 0.88 - 10.44 μg/g) and 22.63 μg/g for chromium (range 8.64 - 95.02 μg/g), indicating that mean background concentrations of arsenic and chromium is the same as or higher than that found at Pond 1. The mean chromium concentration in Pond 2 is elevated relative to the background concentration.

Table 2. Arsenic and chromium concentrations (μg/g dry weight) in sediment from Ponds 1 and 2.

Element	Site	Range (n = 10)	Mean
Arsenic	Pond 1	0.648 - 23.9	2.31
	Pond 2	<0.503 - 6.03	3.62
Chromium	Pond 1	9.39 - 53.2*	18.6
	Pond 2	7.98 - 55.5	46.3

*n = 9; the 10th sample had a chromium concentration of 242 μg/g. Additional sampling and reanalysis of original sample would be necessary to determine if this extreme value is an outlier resulting from analytical error or if the subarea sampled in Pond 1 was a pocket of chromium contamination resulting from a certain refinery process. This value was not included when calculating the geometric mean.

Aquatic Vegetation

Arsenic was slightly elevated in some individual vegetation samples (Table 3, Appendix 4), but the mean concentration from each pond was below 6 µg/g or less reported as typical in pondweed from control sites by Eisler (1988). Pondweed was not collected during the study at Pathfinder National Wildlife Refuge (Ramirez et al. 1995). However, the mean arsenic concentration from pondweed samples (n=40) at the Kendrick Irrigation Project Area in Natrona County was 2.84 µg/g (range = 0.15 to 44.8 µg/g) (See et al. 1992b).

Mean boron concentrations in aquatic vegetation from Ponds 1 and 2 (Table 3) were slightly above the 300 µg/g concentration shown to reduce growth in mallards (Eisler 1990). Boron concentrations in other aquatic vegetation samples taken from various sites in Wyoming regularly exceed this threshold, the result of naturally-occurring boron from geological formations (Dickerson and Ramirez 1997; Dickerson and Ramirez 1993; Ramirez and Armstrong 1992).

Table 3. Trace element concentrations (µg/g dry weight) in *Potamogeton* from Ponds 1 and 2.

Element	Site[a]	Range	Geometric Mean (n=10)
Arsenic	Pond 1	2.17 - 10.2	4.23
	Pond 2	1.75 - 5.88	3.19
Boron	Pond 1	129 - 594	319
	Pond 2	276 - 492	371
Chromium	Pond 1	0.760 - 23.1	2.77
	Pond 2	2.41 - 50.7	7.34
Selenium	Pond 1	0.250 - 9.51	3.64
	Pond 2	1.30 - 5.17	2.77

The mean chromium concentration for aquatic vegetation from Pond 1 was 2.77 µg/g (Table 3) with four out of the ten samples exceeding 4.0 µg/g, the concentration indicative of contamination in biological tissues. The mean concentration in aquatic vegetation from Pond 2 was 7.34 µg/g (Table 3) with eight of the ten samples exceeding 4.0 µg/g. Although several samples exceeded the guideline and were above the mean chromium concentration from pondweed samples (n = 18) collected at the Kendrick Project (mean = 1.2 µg/g; range 0.95 - 10.2 µg/g) (See et al. 1992b), the toxicity of total chromium concentrations over 4.0 µg/g to organisms is unclear because toxicity depends on the chemical form (Eisler 1986). Pondweed samples from this study indicate only that chromium from bottom sediment is incorporated into the plant tissue.

Mean selenium concentrations in vegetation from Ponds 1 and 2 were 3.64 µg/g and 2.77 µg/g, respectively. Although the biological effects threshold to protect fish and birds is 3.0 µg/g, concentrations of 3.0 µg/g to 5.0 µg/g present low to minimal hazard to organisms (Lemly 1993).

Aquatic Invertebrates

Arsenic and chromium were not bioaccumulating in aquatic invertebrates (Appendix 5), an important finding because aquatic invertebrates are a significant source of protein for aquatic bird chicks (Jarvis and Noyes 1986; Serie and Swanson 1976). Only selenium was slightly elevated in aquatic invertebrates collected from Pond 2 (mean [Se] = 4.36 µg/g, range = 4.15 to 4.58 µg/g). Although this mean selenium concentration is above the 3.0 µg/g biological effects threshold to protect fish and birds, it is within the range that Lemly (1993) indicated presents a low to minimal hazard to sensitive species.

Avian Eggs

Chromium concentrations in avian eggs were below detection limit for stilts and four of the five mallard eggs (Table 4; Appendix 6). Chromium was not found in five of the avocet eggs, but the remaining three had concentrations of 8.04, 41.2, and 56.9 µg/g. These concentrations indicate chromium contamination (> 4.0 µg/g) but the toxicological effects to birds is unclear (Eisler 1986). The chromium concentrations in avocet eggs (n=8) from Pathfinder National Wildlife Refuge were below the detection limit of 0.504 (Ramirez et al. 1995) and the chromium concentration in avocet eggs (n=106) from the Kendrick Project was 0.676 µg/g (range = 0.25 to 2.0 µg/g) (See et al. 1992b).

Table 4. Trace element concentrations (µg/g dry weight) in avian eggs from Ponds 1 and 2.

Element	Site	Species	Number of Eggs	Range	Geometric Mean
Chromium	Pond 1	Mallard	5	BDL - 3.92	0.430
	Pond 1	Stilt	8	BDL*	BDL
	Pond 1	Avocet	8	BDL - 56.9	1.43
Selenium	Pond 1	Mallard	5	3.99 - 20.1	8.36
	Pond 1	Stilt	8	4.70 - 23.7	10.9
	Pond 1	Avocet	8	7.30 - 21.3	11.6

* BDL = Below Detection Limit

Selenium concentrations were slightly elevated in avian eggs from Pond 1 (Table 4). The mean selenium concentrations of 10.9 and 11.6 µg/g from stilts and avocets, respectively, at Pond

1 were above the mean background selenium concentration of 5.2 µg/g in avocet eggs from Pathfinder National Wildlife Refuge (Ramirez et al. 1995). However, these concentrations are less than the mean selenium concentration of 81.7 µg/g (range = 24.2 - 135 µg/g) found in avocet eggs (n=106) at the Kendrick Project area where deformities in embryos were documented (See et al. 1992a and 1992b).

According to Skorupa et al. (1996), the mean egg background concentration for selenium should be <3 µg/g with a concentration of <5 µg/g as a maximum background concentration. The onset of adverse effects to sensitive avian species occurs at a mean egg concentration of 8 - 10 µg/g with teratogenic effects occurring at 13 to 24 µg/g. Embryo teratogenicity for ducks occurs when egg concentrations reach 15 µg/g (sensitive species), 30 µg/g for stilts (moderately sensitive), and 40 to 50 µg/g for avocets (Skorupa and Ohlendorf 1991).

Although the selenium concentrations in the avian eggs collected from Pond 1 are slightly greater than the background concentrations in avian eggs from Pathfinder National Wildlife Refuge (Ramirez et al 1995) and the guidelines stated above, the mean egg selenium concentrations were below concentrations shown to cause teratogenesis. The mean selenium concentration in vegetation from Pond 1 was just slightly above the threshold level of 3.0 µg/g, and the selenium concentration in aquatic invertebrates from Pond 1 was less, suggesting that selenium is not biomagnifying and concentrations are naturally occurring rather than the result of any processes conducted by Texaco.

CONCLUSIONS

Data from this study serve as baseline information on the nesting success of aquatic birds and trace element concentrations in abiotic and biotic constituents associated with the North Property ponds. Both Ponds 1 and 2 provide important habitat for a variety of aquatic birds. Waterfowl used Ponds 1 and 2 primarily for resting and feeding. Grebes, avocets and, stilts used the island on Pond 1 for nesting, and although the nests of two pairs of eared grebes were flooded, nesting success for shorebirds using the island was greater than 90%. The island provided the bare ground necessary for nesting shorebirds without the threat of terrestrial predators.

Very little nesting activity was observed for waterfowl and shorebirds at Pond 2 but coots and phalaropes preferred the shallow water and emergent vegetation at Pond 2 for nesting. The shallow water and emergent vegetation at Pond 2 also provided important habitat for invertebrates as evidence by the collection of invertebrate samples for this study and the number of shorebirds consistently observed feeding there.

Trace elements were not present in Ponds 1 and 2 at concentrations likely to adversely affect feeding or nesting aquatic birds. Although chromium concentrations were elevated in some samples, the potential for these concentrations to affect aquatic birds is unknown. Arsenic was slightly elevated in some samples but concentrations were comparable to background concentrations at Pathfinder National Wildlife Refuge. Boron and selenium concentrations were slightly elevated in samples from the ponds. These concentrations are most likely naturally occurring due to the geological formations in the area. There was no indication of significant bioaccumulation of any trace elements in the aquatic food chain. These parameters should be sampled and analyzed for prior to any future changes in current management activities of the ponds.

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Appendix 1. Basic water chemistry of water from Ponds 1 and 2, former Texaco Refinery. All units in mg/L unless otherwise noted.

Sample Site	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl
Pond 1	133.6	185.6	655.1	4.6	<0.1	502.0	1825.2	96.3
Pond 2	306.9	274.4	1131	19	<0.1	553.7	2635.1	668

Sample Site	B	NO_3-N	pH	Conductivity (µmhos/cm)	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$	Total Dissolved Solids
Pond 1	0.55	0.1	8.4	3,650	1,096	411	3,403
Pond 2	1.23	0.4	8.2	7,410	1,894	454	5,591

Appendix 2. Trace element concentrations (mg/L) in water from Ponds 1 and 2, former Texaco Refinery.

Water Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg
Pond 1										
TXP1WA01	0.163	0.0062	0.548	0.0343	<0.0006	<0.0006	<0.0056	<0.0056	0.101	<0.0025
TXP1WA02	0.145	0.0074	0.551	0.0349	<0.0006	<0.0006	<0.0056	<0.0056	0.0881	<0.0025
TXP1WA03	0.154	0.0065	0.541	0.0378	<0.0006	<0.0006	<0.0056	<0.0056	0.154	<0.0025
TXP1WA04	0.163	0.0056	0.547	0.0318	<0.0006	<0.0006	<0.0056	<0.0056	0.0949	<0.0025
TXP1WA05	0.151	0.044	0.685	0.0244	<0.0006	<0.0006	<0.0056	<0.0056	0.882	<0.0025
TXP1WA06	0.130	0.0089	0.519	0.0314	<0.0006	<0.0006	<0.0056	<0.0056	0.0808	<0.0025
TXP1WA07	0.126	0.0028	0.514	0.0299	<0.0006	<0.0006	<0.0056	<0.0056	0.0678	<0.0025
TXP1WA08	0.146	0.0086	0.493	0.0368	<0.0006	<0.0006	<0.0056	<0.0056	0.168	<0.0025
TXP1WA09	0.159	0.0076	0.527	0.0306	<0.0006	<0.0006	<0.0056	<0.0056	0.111	<0.0025
Pond 2										
TXP2WA01	0.142	0.0082	0.939	0.0232	<0.0006	<0.0006	<0.0056	<0.0056	0.197	<0.0025
TXP2WA02	0.108	0.0064	0.647	0.0290	<0.0006	<0.0006	<0.0056	<0.0056	0.0916	<0.0025
TXP2WA03	0.0987	0.0058	0.689	0.0304	<0.0006	<0.0006	<0.0056	<0.0056	0.0943	<0.0025
TXP2WA04	0.0921	0.0074	0.712	0.0286	<0.0006	<0.0006	<0.0056	<0.0056	0.0761	<0.0025
TXP2WA05	0.115	0.010	0.932	0.0251	<0.0006	<0.0006	<0.0056	<0.0056	0.163	<0.0025
TXP2WA06	0.0755	0.0081	0.974	0.0221	<0.0006	<0.0006	<0.0056	<0.0056	0.0821	<0.0025
TXP2WA07	0.190	0.011	0.974	0.0227	<0.0006	<0.0006	<0.0056	<0.0056	0.157	<0.0025
TXP2WA08	0.161	0.0076	0.711	0.0230	<0.0006	<0.0006	<0.0056	<0.0056	0.136	<0.0025
TXP2WA09	0.123	0.0064	0.653	0.0217	<0.0006	<0.0006	<0.0056	<0.0056	0.0504	<0.0025

Appendix 2. cont.

Water Sample #	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Pond 1									
TXP1WA01	352	0.275	0.0057	<0.0056	<0.0111	<0.0056	1.20	<0.0044	0.0670
TXP1WA02	357	0.265	0.0022	<0.0056	<0.0111	<0.0056	1.23	<0.0044	0.0676
TXP1WA03	351	0.294	0.0052	<0.0056	<0.0111	<0.0056	1.28	<0.0044	0.0663
TXP1WA04	339	0.243	0.0063	<0.0056	<0.0111	<0.0056	1.16	<0.0044	0.0571
TXP1WA05	391	1.50	0.017	<0.0056	<0.0111	<0.0056	1.26	<0.0044	0.0571
TXP1WA06	335	0.282	0.0022	<0.0056	<0.0111	<0.0056	0.989	<0.0044	0.0647
TXP1WA07	335	0.203	0.0055	<0.0056	<0.0111	<0.0056	0.965	<0.0044	0.0680
TXP1WA08	321	0.342	0.0022	<0.0056	<0.0111	<0.0056	1.08	<0.0044	0.0665
TXP1WA09	334	0.212	0.0045	<0.0056	<0.0111	<0.0056	0.992	<0.0044	0.0641
Pond 2									
TXP2WA01	358	0.238	0.0435	<0.0056	<0.0111	<0.0056	1.83	<0.0044	0.0564
TXP2WA02	357	0.0579	0.0146	<0.0056	<0.0111	<0.0056	1.27	<0.0044	0.0558
TXP2WA03	362	0.0599	0.0170	<0.0056	<0.0111	<0.0056	1.34	<0.0044	0.0562
TXP2WA04	366	0.0365	0.0175	<0.0056	0.0119	<0.0056	1.34	<0.0044	0.0562
TXP2WA05	352	0.115	0.0426	<0.0056	<0.0111	<0.0056	1.77	<0.0044	0.0551
TXP2WA06	436	0.134	0.0265	<0.0056	0.0114	<0.0056	1.60	<0.0044	0.0563
TXP2WA07	440	0.186	0.0268	<0.0056	<0.0111	<0.0056	1.69	<0.0044	0.0628
TXP2WA08	404	0.0546	0.0131	<0.0056	0.0116	<0.0056	1.09	<0.0044	0.0637
TXP2WA09	385	0.0388	0.0132	<0.0056	<0.0111	<0.0056	1.04	<0.0044	0.0606

Appendix 3. Trace element concentrations (µg/g dry weight) in sediment from Ponds 1 and 2, former Texaco Refinery.

Sediment Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg
Pond 1										
TXP1SD01	723.0	0.760	2.11	14.1	<0.100	<0.100	9.39	0.977	1339.0	<0.100
TXP1SD02	884.0	0.898	2.11	19.3	<0.0998	<0.0998	11.8	1.35	2115.0	<0.0998
TXP1SD03	510.0	0.648	<2.02	12.6	<0.101	<0.101	13.4	0.944	1119.0	<0.101
TXP1SD04	684.0	1.41	3.02	34.9	<0.100	<0.100	37.4	1.91	1637.0	<0.100
TXP1SD05	588.0	0.949	2.03	20.8	<0.101	<0.101	15.8	1.36	1485.0	<0.101
TXP1SD06	1401	2.83	2.80	25.6	<0.100	<0.100	53.2	3.30	2326.0	<0.100
TXP1SD07	4084	23.9	13.6	80.9	0.180	0.344	242	21.5	7781.0	<0.101
TXP1SD08	499.0	2.82	4.33	15.6	<0.0994	0.106	11.4	1.74	2555.0	<0.0994
TXP1SD09	2170	17.9	46.3	97.2	0.143	0.355	11.5	7.64	10590	<0.101
TXP1SD10	1792	2.15	4.63	28.7	<0.101	<0.101	43.0	3.13	2427.0	<0.101
Pond 2										
TXP2SD01	2249	3.76	20.2	75.7	0.182	0.288	55.5	5.19	4269.0	<0.100
TXP2SD02	746.0	<0.503	<2.01	16.2	<0.101	<0.101	28.5	1.00	1602.0	<0.101
TXP2SD03	4285	3.83	29.6	133	0.236	0.466	46.1	8.6	8273.0	<0.0990
TXP2SD04	3153	3.13	43.6	119	0.213	0.443	37.3	9.15	8658.0	<0.101
TXP2SD05	3529	3.05	22.9	98.3	0.230	0.426	29.5	7.85	8590.0	<0.100
TXP2SD06	3912	5.94	39.4	129	0.219	0.410	45.0	8.45	8828.0	<0.101
TXP2SD07	3122	6.03	43.8	124	0.196	0.387	51.7	9.24	8618.0	<0.101
TXP2SD08	3307	3.15	24.8	111	0.204	0.373	33.6	7.04	7554.0	<0.101
TXP2SD09	2671	2.10	16.8	48.2	0.158	0.243	7.98	3.25	4575.0	<0.101
TXP2SD10	3278	3.26	33.5	125	0.178	0.530	44.3	10.6	9482.0	<0.0998

Appendix 3. cont.

Sediment Sample #	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Pond 1									
TXP1SD01	396.00	18.00	0.589	1.42	2.63	<0.500	11.10	2.12	5.71
TXP1SD02	665.00	49.00	1.92	2.19	4.25	0.630	54.40	2.73	10.5
TXP1SD03	365.00	23.00	0.908	1.54	3.53	<0.506	30.10	1.71	8.73
TXP1SD04	558.00	43.30	3.42	3.04	7.92	1.12	49.80	2.78	16.6
TXP1SD05	421.00	22.80	1.54	2.06	5.96	<0.505	42.90	1.65	13.1
TXP1SD06	1350.0	87.80	<0.500	3.72	5.34	0.923	109.0	3.87	38.8
TXP1SD07	9977.0	241.0	0.876	7.20	17.2	6.02	320.0	7.79	207
TXP1SD08	571.00	96.60	<0.497	2.42	3.04	<0.497	21.30	1.73	22.4
TXP1SD09	4286.0	2494	4.38	9.73	14.9	1.64	259.0	8.01	29.3
TXP1SD10	1018.0	48.00	2.89	3.49	8.18	0.996	53.20	6.35	22.9
Pond 2									
TXP2SD01	2465.0	290.0	4.70	11.4	14.5	1.98	279.0	8.25	29.2
TXP2SD02	378.00	18.10	<0.503	4.24	2.55	<0.503	5.780	2.08	2.98
TXP2SD03	4645.0	239.0	1.94	11.4	19.8	4.92	655.0	12.0	47.6
TXP2SD04	10760	309.0	1.43	10.8	18.8	4.36	908.0	9.50	49.0
TXP2SD05	4757.0	265.0	3.00	9.36	14.8	2.15	1004	9.80	37.5
TXP2SD06	7309.0	330.0	3.40	12.2	20.0	4.47	748.0	11.9	47.7
TXP2SD07	6742.0	357.0	5.92	13.2	23.8	5.03	654.0	10.5	51.8
TXP2SD08	6283.0	230.0	1.79	10.4	18.1	3.65	406.0	10.3	38.4
TXP2SD09	3341.0	210.0	1.20	4.18	8.13	0.728	167.0	5.98	24.0
TXP2SD10	7502.0	1535	42.0	13.5	23.5	5.96	1692	10.7	52.4

Appendix 4. Trace element concentrations (µg/g dry weight) in *Potamogeton* from Ponds 1 and 2, former Texaco Refinery.

Vegetation Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg
Pond 1										
TXP1AV01	100	2.54	268	103	<0.101	0.118	4.51	3.52	528.0	<0.101
TXP1AV02	189	5.26	194	121	<0.101	0.160	6.87	4.79	1110	<0.101
TXP1AV03	55.4	10.2	313	40.6	<0.100	<0.100	1.58	1.96	1964	<0.100
TXP1AV04	54.0	9.37	344	48.7	<0.101	0.137	1.82	1.13	2092	<0.101
TXP1AV05	14.9	3.09	594	69.7	<0.102	<0.102	0.763	1.06	141.0	<0.102
TXP1AV06	128	4.24	421	106	<0.0998	<0.0998	9.11	1.75	489.0	<0.0998
TXP1AV07	309	5.56	129	133	<0.103	<0.103	23.1	2.22	1046	<0.103
TXP1AV08	16.1	3.05	535	83.2	<0.101	<0.101	1.40	1.17	145.0	<0.101
TXP1AV09	32.5	2.89	313	117	<0.100	<0.100	1.46	0.878	162.0	<0.100
TXP1AV10	33.1	2.17	361	140	<0.102	<0.102	0.910	0.803	132.0	<0.102
Pond 2										
TXP2AV01	70.1	2.23	362	31.4	<0.102	<0.102	2.42	1.59	620.0	<0.102
TXP2AV02	128	2.36	314	30.0	<0.101	<0.101	4.47	2.10	812.0	<0.101
TXP2AV03	73.2	1.75	385	29.6	<0.101	<0.101	2.41	1.52	472.0	<0.101
TXP2AV04	162	2.80	408	36.1	<0.101	0.131	4.44	2.61	975.0	<0.101
TXP2AV05	63.7	4.06	473	45.6	<0.0998	<0.0998	5.93	1.68	577.0	<0.0998
TXP2AV06	79.2	3.44	492	82.7	<0.101	0.149	6.03	1.65	404.0	<0.101
TXP2AV07	336	3.56	276	78.4	<0.101	0.250	50.7	2.36	971.0	<0.101
TXP2AV08	126	2.94	347	82.0	<0.101	0.145	11.4	2.01	369.0	<0.101
TXP2AV09	146	4.93	432	89.9	<0.100	0.186	8.47	2.25	750.0	<0.100
TXP2AV10	140	5.88	291	68.7	<0.101	<0.101	22.3	2.55	634.0	<0.101

Appendix 4. cont.

Vegetation Sample #	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Pond 1									
TXP1AV01	6119.0	1740	2.34	4.13	1.81	6.02	2808	0.744	61.3
TXP1AV02	5696.0	3400	2.80	4.82	3.04	7.70	2744	1.24	69.3
TXP1AV03	8810.0	1068	7.10	2.63	1.57	<0.502	138.0	<0.502	43.4
TXP1AV04	9037.0	1473	7.28	2.85	<1.01	<0.503	137.0	<0.503	29.0
TXP1AV05	9961.0	2651	2.46	2.56	<1.02	6.46	1386	<0.509	41.0
TXP1AV06	5680.0	4073	1.64	3.00	3.15	7.70	2079	0.831	31.2
TXP1AV07	4708.0	5406	1.93	4.64	5.65	9.51	2108	1.68	124
TXP1AV08	9034.0	2522	1.98	3.12	<1.01	7.68	1587	<0.505	36.8
TXP1AV09	5448.0	1364	1.88	2.78	1.58	6.61	2947	<0.502	30.2
TXP1AV10	4684.0	1219	1.79	2.48	1.15	5.80	3574	<0.508	25.4
Pond 2									
TXP2AV01	11090	5617	7.54	2.71	4.34	2.00	1921	0.567	39.2
TXP2AV02	10430	5831	8.47	2.86	2.98	1.96	1336	0.689	60.3
TXP2AV03	11550	4207	6.46	2.08	1.35	1.42	2115	<0.503	55.4
TXP2AV04	9967.0	4656	8.54	3.35	4.20	2.12	1694	0.877	92.4
TXP2AV05	11910	5429	6.57	2.34	2.54	1.30	611.0	0.662	80.3
TXP2AV06	10210	2353	3.45	2.39	2.62	4.17	2102	0.648	35.2
TXP2AV07	8297.0	2237	3.79	3.72	2.90	5.17	1979	1.53	86.5
TXP2AV08	9531.0	1586	4.31	2.28	1.27	3.79	2430	0.824	88.0
TXP2AV09	9667.0	5242	4.94	3.68	5.28	4.65	1813	0.998	87.5
TXP2AV10	8407.0	2696	4.12	3.56	2.28	4.60	1402	1.05	152

Appendix 5. Trace element concentrations (µg/g dry weight) in damselfly larvae from Ponds 1 and 2, former Texaco Refinery.

Invertebrate Sample #	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg
Pond 1										
TXP1A101	31.5	4.06	11.0	24.8	<0.103	<0.103	<0.513	5.73	427.0	<0.103
TXP1A102	19.9	3.46	12.9	7.11	<0.101	<0.101	<0.504	5.12	287.0	<0.101
TXP1A103	23.6	3.78	9.80	25.0	<0.102	0.118	<0.510	4.57	451.0	<0.102
TXP1A104	21.5	3.79	8.54	29.6	<0.102	<0.102	<0.509	4.65	360.0	<0.102
TXP1A105	35.7	3.65	9.51	13.4	<0.102	<0.102	0.558	5.68	353.0	<0.102
TXP1A106	30.2	4.23	8.50	24.4	<0.0994	<0.0994	0.507	4.60	466.0	<0.0994
TXP1A107	37.4	4.82	5.00	23.4	<0.101	<0.101	0.560	4.82	624.0	<0.101
TXP1A108	61.8	6.72	7.40	36.5	<0.102	<0.102	0.582	4.44	1185	<0.102
TXP1A109	30.8	3.85	8.77	13.1	<0.101	<0.101	0.631	4.97	357.0	<0.101
TXP1A110	26.3	4.06	9.10	35.8	<0.0996	0.106	0.574	4.02	412.0	<0.0996
Pond 2										
TXP2A101	34.4	1.38	8.78	1.88	<0.102	<0.102	0.592	10.0	115.0	0.142
TXP2A102	18.8	1.11	4.84	1.69	<0.100	<0.100	0.564	8.74	106.0	0.142
TXP2A103	37.0	1.54	7.23	2.41	<0.101	<0.101	0.682	10.1	144.0	0.162
TXP2A104	31.3	1.09	7.71	1.78	<0.101	<0.101	<0.503	9.23	109.0	0.139
TXP2A105	18.9	1.11	5.09	1.31	<0.101	<0.101	<0.504	8.93	95.00	0.120
TXP2A106	29.0	1.10	6.17	1.70	<0.100	<0.100	0.599	9.55	119.0	0.158
TXP2A107	37.7	1.20	8.07	1.93	<0.101	<0.101	1.57	9.30	134.0	0.148
TXP2A108	21.8	1.21	7.91	1.50	<0.0992	<0.0992	<0.496	8.16	90.70	0.134
TXP2A109	45.1	0.864	7.35	1.98	<0.102	<0.102	0.682	9.81	130.0	0.147
TXP2A110	20.3	0.974	5.45	1.40	<0.101	<0.101	<0.507	8.34	88.50	0.138

Appendix 5. cont.

Invertebrate Sample #	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Pond 1									
TXP1A101	2312	90.8	<0.513	0.514	<1.03	1.89	23.8	<0.513	63.3
TXP1A102	2124	85.1	<0.504	<0.504	<1.01	2.00	16.2	<0.504	66.8
TXP1A103	1386	95.6	<0.510	0.519	1.21	2.14	27.5	<0.510	58.9
TXP1A104	2121	91.0	<0.509	<0.509	1.28	2.00	19.3	<0.509	63.0
TXP1A105	1911	81.5	<0.510	0.522	<1.02	2.04	17.9	<0.510	69.2
TXP1A106	2278	102	<0.497	<0.497	<.994	1.95	19.3	<0.497	67.2
TXP1A107	2240	139	<0.504	<0.504	<1.01	1.79	33.9	<0.504	64.5
TXP1A108	2035	127	<0.508	<0.508	<1.02	1.77	34.8	<0.508	60.8
TXP1A109	2215	103	<0.503	<0.503	<1.01	2.12	19.9	<0.503	61.2
TXP1A110	2179	106	<0.498	<0.498	<.996	1.96	21.0	<0.498	61.4
Pond 2									
TXP2A101	2323	181	1.06	<0.508	<1.02	4.25	33.6	<0.508	50.5
TXP2A102	907.0	168	0.506	0.550	<1.00	4.29	18.2	<0.502	39.9
TXP2A103	2009	222	1.02	0.588	<1.01	4.37	29.0	<0.505	52.8
TXP2A104	1907	169	0.83	<0.503	<1.01	4.34	23.2	<0.503	44.2
TXP2A105	1562	169	0.819	<0.504	<1.01	4.50	20.6	<0.504	41.2
TXP2A106	1648	169	0.680	<0.500	<1.00	4.15	21.4	<0.500	45.4
TXP2A107	1446	192	0.747	<0.504	<1.01	4.58	27.0	<0.504	44.5
TXP2A108	1362	152	0.666	<0.496	<.992	4.29	16.8	<0.496	39.5
TXP2A109	1619	186	0.716	0.515	<1.02	4.54	31.7	<0.508	48.8
TXP2A110	1090	149	<0.507	<0.507	<1.01	4.29	15.2	<0.507	39.8

Appendix 6. Trace element concentrations (μg/g dry weight) in avian eggs at Ponds 1 and 2, former Texaco Refinery.

Avian Egg Sample #	Common Name	Al	As	B	Ba	Be	Cd	Cr	Cu
Pond 1									
TXP1AA01	American Avocet	12.1	<0.497	<1.99	0.947	<0.0994	<0.0994	<0.497	3.54
TXP1AA02	American Avocet	9.75	<0.496	<1.98	0.662	<0.0992	<0.0992	<0.496	2.58
TXP1AA03	American Avocet	11.3	<0.495	<1.98	0.974	<0.0990	<0.0990	<0.495	3.44
TXP1AA04	American Avocet	11.8	<0.513	<2.05	0.977	<0.103	<0.103	8.04	3.82
TXP1AA05	American Avocet	9.23	0.880	<1.96	2.65	<0.0982	<0.0982	<0.491	3.86
TXP1AA06	American Avocet	8.93	<0.501	<2.00	2.37	<0.100	<0.100	<0.501	3.54
TXP1AA07	American Avocet	15.3	<0.501	<2.00	1.18	<0.100	<0.100	41.2	3.91
TXP1AA08	American Avocet	15.6	<0.494	<1.98	1.67	<0.0988	<0.0988	56.9	4.00
TXP1BS01	Black-necked stilt	9.22	<0.492	<1.97	0.871	<0.0984	<0.0984	<0.492	3.24
TXP1BS02	Black-necked stilt	7.11	<0.503	<2.01	1.10	<0.101	<0.101	<0.503	3.30
TXP1BS03	Black-necked stilt	6.21	<0.499	<2.00	0.753	<0.0998	<0.0998	<0.499	3.59
TXP1BS04	Black-necked stilt	10.6	<0.502	<2.01	<0.502	<0.100	<0.100	<0.502	3.18
TXP1BS05	Black-necked stilt	13.7	<0.502	<2.01	1.56	<0.100	<0.100	<0.502	3.28
TXP1BS11	Black-necked stilt	11.8	<0.509	<2.04	1.42	<0.102	<0.102	<0.509	3.31
TXP1BS12	Black-necked stilt	11.5	<0.509	<2.04	1.66	<0.102	<0.102	<0.509	3.13
TXP1BS13	Black-necked stilt	12.2	<0.492	<1.97	1.17	<0.0984	<0.0984	<0.492	3.11
TXP1EG01	Eared Grebe	13.6	<0.498	<1.99	<0.498	<0.0996	<0.0996	<0.498	2.80
TXP1EG02	Eared Grebe	12.6	<0.497	<1.99	1.04	<0.0994	<0.0994	<0.497	2.96
TXP1MA01	Mallard	10.6	<0.506	<2.02	3.76	<0.101	<0.101	<0.506	3.30
TXP1MA02	Mallard	9.70	<0.504	<2.02	4.34	<0.101	<0.101	<0.504	2.44
TXP1MA03	Mallard	29.0	<0.505	<2.02	3.11	<0.101	<0.101	3.92	4.12
TXP1MA04	Mallard	14.6	<0.496	<1.98	0.578	<0.0992	<0.0992	<0.496	2.91
TXP1MA05	Mallard	8.18	<0.495	<1.98	4.68	<0.0990	<0.0990	<0.495	3.08
Pond 2									
TXP2DU01	Unknown	7.25	<0.495	<1.98	5.69	<0.0990	<0.0990	<0.495	3.48

Appendix 6. cont.

Avian Egg Sample #	Common Name	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se
Pond 1									
TXP1AA01	American Avocet	97.4	0.217	455	2.34	<0.497	<0.497	<0.99	8.06
TXP1AA02	American Avocet	111	0.398	400	2.32	<0.496	<0.496	<0.99	10.6
TXP1AA03	American Avocet	118	0.904	412	4.67	<0.495	<0.495	<0.99	11.3
TXP1AA04	American Avocet	158	0.447	414	2.75	1.320	0.564	<1.03	21.3
TXP1AA05	American Avocet	103	0.219	511	2.54	<0.491	<0.491	<0.98	8.25
TXP1AA06	American Avocet	102	<0.100	446	2.16	<0.501	<0.501	<1.00	7.30
TXP1AA07	American Avocet	439	0.301	501	6.51	0.763	1.740	<1.00	15.0
TXP1AA08	American Avocet	513	1.570	684	8.36	0.927	3.730	1.33	17.6
TXP1BS01	Black-necked stilt	97.8	0.826	443	1.77	<0.492	<0.492	1.47	10.2
TXP1BS02	Black-necked stilt	96.5	1.130	424	2.94	<0.503	<0.503	<1.01	18.5
TXP1BS03	Black-necked stilt	100	1.440	389	2.56	<0.499	<0.499	<1.00	18.6
TXP1BS04	Black-necked stilt	71.8	0.327	404	1.51	<0.502	<0.502	<1.00	4.70
TXP1BS05	Black-necked stilt	116	1.280	452	2.10	<0.502	<0.502	<1.00	23.7
TXP1BS11	Black-necked stilt	124	0.289	462	1.62	<0.509	<0.509	<1.02	6.20
TXP1BS12	Black-necked stilt	88.7	0.257	474	1.62	<0.509	<0.509	<1.02	6.06
TXP1BS13	Black-necked stilt	99.7	0.925	440	1.52	<0.492	<0.492	<0.98	13.3
TXP1EG01	Eared Grebe	132	0.584	387	3.36	<0.498	<0.498	<1.00	28.5
TXP1EG02	Eared Grebe	133	0.389	491	2.24	<0.497	<0.497	<0.99	34.2
TXP1MA01	Mallard	130	<0.101	328	4.38	<0.506	<0.506	<1.01	4.23
TXP1MA02	Mallard	127	<0.101	301	4.35	<0.504	<0.504	<1.01	3.99
TXP1MA03	Mallard	137	<0.101	559	2.56	<0.505	<0.505	<1.01	13.1
TXP1MA04	Mallard	60.3	<0.099	254	<0.40	<0.496	<0.496	<0.99	9.17
TXP1MA05	Mallard	105	0.190	364	4.61	<0.495	<0.495	<0.99	20.1
Pond 2									
TXP2DU01	Unknown	110	0.616	312	6.72	<0.495	<0.495	1.04	16.2

Appendix 6. cont.

Avian Egg Sample #	Common Name	Sr	V	Zn
Pond 1				
TXP1AA01	American Avocet	22.1	<0.497	48.1
TXP1AA02	American Avocet	27.8	<0.496	37.9
TXP1AA03	American Avocet	26.2	<0.495	50.0
TXP1AA04	American Avocet	28.8	<0.513	51.5
TXP1AA05	American Avocet	26.4	<0.491	46.9
TXP1AA06	American Avocet	28.2	<0.501	40.6
TXP1AA07	American Avocet	22.2	<0.501	55.4
TXP1AA08	American Avocet	55.1	<0.494	87.2
TXP1BS01	Black-necked stilt	21.1	<0.492	37.9
TXP1BS02	Black-necked stilt	15.1	<0.503	45.0
TXP1BS03	Black-necked stilt	15.9	<0.499	38.0
TXP1BS04	Black-necked stilt	11.4	<0.502	41.8
TXP1BS05	Black-necked stilt	20.9	<0.502	43.8
TXP1BS11	Black-necked stilt	14.4	<0.509	48.3
TXP1BS12	Black-necked stilt	14.0	<0.509	48.4
TXP1BS13	Black-necked stilt	23.1	<0.492	43.4
TXP1EG01	Eared Grebe	9.13	<0.498	57.8
TXP1EG02	Eared Grebe	12.1	<0.497	48.2
TXP1MA01	Mallard	11.4	<0.506	47.9
TXP1MA02	Mallard	11.0	<0.504	51.1
TXP1MA03	Mallard	58.0	<0.505	110
TXP1MA04	Mallard	8.06	<0.496	56.4
TXP1MA05	Mallard	22.3	<0.495	41.7
Pond 2				
TXP2DU01	Unknown	12.3	<0.495	49.4